PHYSICAL – METALLURGICAL FUNDAMENTAL CONCEPT OF CRACKING OF CONTINUOUSLY CAST PRODUCTS

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FYZIKÁLNO – METALURGICKÁ PODSTATA KREHNUTIA OCEĽOVÝCH KONTIODLIATKOV

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Abstrakt

Príspevok sa zaoberá analýzou a vysvetľovaním podstaty krehnutia oceľových kontiodliatkov (brám, blokov, sochorov) spojeného so vznikom mikrotrhlín a trhlín v povrchovej kôre. V príspevku sú uvedené základné východiská a predpoklady krehnutia kontiodliatkov, rizikové faktory horúceho praskania a pravdepodobné procesy rastovej podsolidusovej rekryštalizácie prebiehajúcej pri vysokých teplotách 1300 – 1400 °C pri plynulom odlievaní ocelí.

Z urobenej analýzy vyplýva záver, že drvivá väčšina priečnych, rozvetvených (sieťových) a pozdĺžnych trhlín vzniká v kryštalizátore, pričom trhliny môžu, ale nemusia rásť do väčšej hĺbky kontiodliatku, či už v zóne sekundárneho chladenia, alebo v etape rovnania kontiodliatku.

Rast trhlín pri plynulom odlievaní bude kontrolovaný relaxačnou schopnosťou matrice eliminovať špičky napätí na hrote trhlín. Relaxácia napätí sa uskutočňuje plastickou deformáciou – creepom, precipitáciou karbidických, nitridických alebo karbonitridických fáz, alebo segregáciou S, P a ďalších povrchovoaktívnych prvkov.

Abstract

The basis of embrittlement of continuously cast products (slabs, blocks, billets) in connection with the development of micro cracks and cracks in the surface skin is analyzed and described in the contribution.

Basic starting points and provisions of the embrittlement of continuously cast products, risk factors of hot cracking and probable processes of under solidus recrystallization grain growth at high temperature from 1300 up to 1400 ºC during continuous casting are presented.

Based on the analysis a conclusion made, the majority of transversal, branched, and longitudinal cracks is formed in the mould, and these cracks can, though need not, grow on deeper into the slab either in the secondary cooling zone or in the straightening process.

The crack growth during continuous casting is controlled by the ability of the matrix to relax stress peaks in front of crack tips. The stress relaxation is due to the plastic deformation

(creep), the precipitation of carbidic, nitridic or carbonitridic phases or segregation of S, and/or P or other surface active elements.

Keywords: friction, stress, micro-crack, crack, peritectic transformation, austenite grain, dendrite, under solidus recrystallization growth

1. Basis and assumptions

a) The solidification of the surface skin in the mould is completed in complex conditions of liquid steel flow and turbulence during the growth of the moving surface skin on one side and intense heat transfer into the oscillating water cooled crystallizer walls on the other.

b) The friction between the skin and mould walls in the upper part of the crystallizer is sliding friction. In the lower part of the crystallizer it is rolling friction. Due to friction between the oscillating crystallizer and the surfaces of the slab, axial stress fields are built up in the solidified surface skin.

c) Due to the temperature gradients in the direction of the solidified surface skin and in the direction along the slab, thermal stress fields are built up in the solidified skin. In general, axial tensile stress in the surface of the skin and axial compression stress are built up in the vicinity of the crystallization front caused by the combination of the axial and perpendicular thermal gradients.

d) Skin stress fields are built up by both skin shrinkage and by the ferro-static pressure of the liquid steel, too. The shrinkage is causing that the slab has a tendency to pull away from the mould wall, the ferro-static pressure is acting in the opposite direction and keeps the contact of the solid skin with the crystallizer walls.

e) The axial tensile stress in the solidified skin is growing by the gravitation increase with the mass of the slab and pulling force on the slab. There is an axial force equal to the total sum of gravitation force and pulling force on the slab.

f) Fine micro-cracks initiate (about 10^{-1} mm deep) in the surface skin of continuously cast slabs during the solidification in the mould. These cracks do not propagate deeper due to the plastic deformation ability of the surface skin, and its ability to relax the stress peaks in the crack tips. These micro cracks can be revegled by metallography only.

g) Nucleation and growth of micro cracks exceeding the critical length is inter dendritic, occur on the boundaries of dendrites (or similarly oriented dendrite clusters), or it is intercrystalline on coarse γ – austenite grain boundaries.

h) All, the critical local stress, intercrystalline fracture and the deformation and relaxation properties of the matrix are influenced markedly by segregation and processes on grain boundaries. Generally, the coarser the microstructure the larger the stress maximum values. This way, coarser microstructures are more sensitive to intercrystalline damage.

i) In general, hot cracks are formed if the deformation caused by solidification, cooling or external forces is higher then the ductility of the steel in the local point of the skin.

2. Risk factors of hot cracking

a) Some materials have higher susceptibility to hot cracking, for instance peritectic steel. Peritectic steels have the shrinkage during the peritectic transformation twice as high as common steel types. Due to the higher volume shrink, the contraction of the skin is uneven and local deformations (depressions) occur in the slab in the direction of pulling or in oscillation waves – chill marks.

b) The second more serious and not explained phenomenon yet, is the formation of coarse austenite grains (up to a few mm) in the surface skin. They are formed, as supposed, after the completion of the peritectic reaction at temperatures over 1350 ºC. It is evidenced by open surfaces of cracks forming intercrystalline surfaces – shell like brittle fracture surfaces, like stone fractures. There are still mysterious processes of so called. „grain granulation“, with recrystallization in the dendrite boundary areas when original meandering boundaries are straitened and replaced by smooth straight boundaries. It is still not clear why one dendrite is divided into a number of grains while on the other side a number of dendrites is able to form a single „prime γ – grain“.

c) An other important factor is the deep oscillation marks, forming a notch and decreasing the high temperature ductility of the surface skin. Deep oscillation waves are formed first at low casting rate, at the change of the tundish or in the first slabs after the change of the tundish, after alarms on security thermocouples, or after continuously cast slab width changes.

3. Under solidus recrystallization grain growth during continuous casting and the possible consequence

Processis of under solidus grain growth recrystallization taking part in mould resulting in coarse real γ grains very likely influence the slab skin embrittlement and formation of crack during continuous casting. The recrystallization of dendrite boundary area in ideal conditions is based on the original meandering boundaries, and one dendrite is transformed into one austenite grain. If dendrites form a parallel cluster of dendrites (frequent in the cast skin) the boundary straightening is connected with the integration of neighbouring dendrites and the disappearance of grain boundaries among them. The under solidus recrystallization growth processes are very fast due to the very high temperature of the skin surface under the meniscus (about. 1300 to 1400 ºC). The driving force is the decrease of the surface energy. Coarse – austenite grain boundaries are the preferred locations for the deposition of Cu particles coming from the abrasion of the mould (in cases when the nickel layer is worn out or the mould was not plated at all). This can lead to the development of branched crack patterns. The next cause of γ – grain boundary weakening is the deposition of particles like sulphides, oxides, nitrides at the grain boundaries and the segregation of surface active elements Cu, P, As, Sb, Sn, if they are present in the steel in higher concentrations (first in eletrical steel). All the mentioned precipitates and elements can initiate micro cracks at low tensile forces. The cracks are interconnected and grow into macroscopic cracks. The growth of micro cracks is supported by oxidation on the grain boundaries and the formation of oxide Fe_2O_3 films, with the tendency to increase its volume. All the mentioned processes take place in the crystallizer. They can be enhanced by unsuitable casting conditions e.g. low casting rate, unsuitable crystallizer oscillations, etc.

At low casting rate, e.g. at the change of the tundish, surface skin is exposed to the high temperature longer, causing the development of deeper oscillation marks. The conditions in the roots of deeper oscillation marks allow the formation of coarse γ grains as well as the initiation of transversal cracks supported by the presence of impurities and segregated elements.
A special case of the surface skin solidification can develop, where the boundaries between dendrites are weakened before the grain growth recrystallization. Sulphides, oxisulphides

carbosulphides, deposited at the dendrite boundaries can reduce the cohesion of the boundaries between them so much, that the growth recrystallization of these boundaries can not be completed, but inter dendritic cracks develop, grow in the centre of the continuously cast slab. Sometimes the cracks grow also in the direction to the slab surface and can cause the breaking of the surface skin of the slab.

4. Conclusion

According to the described analysis it can be concluded, that the majority of transversal, branched and longitudinal cracks is initiated and developed in the crystallizer. Micro-cracks can develop in the surface skin in the mould very frequently. The steel grade and other different factors decide the following development of the cracks. Advanced crack propagation to larger depth (1 – 3 mm, or 3 – 8 mm and more) relays on the steel grade and other factors (peritectic steel is the most sensitive – volume changes, coarse γ – grain, etc.). Micro-cracks can, though need not, grow on in the secondary cooling zone or in the straightener zone.

The crack growth in continuously cast slabs is controlled by the ability of the matrix to relax stress peaks in front of crack tips, and to avoid their propagation deeper. The stress relaxation is dueto the plastic deformation-creep. Creep concentrates at the grain boundaries. Besides the creep – slip in grain boundary area there is the precipitation of sulfidic, carbidic, nitridic or carbonitridic phases. Creep processes + precipitates result information of cavities and the coalescence of cavities leads to intercrystalline cracks. Another mechanism acting mainly in electric steel is the segregation of S, and/or P or other surface active elements (Sn, Sb, As, Cu) at grain boundaries. In the straightening zone the cracks can propagate deeper what and this again depends on the ability of the matrix to relax stress on the sharpness of the crack tip etc.

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